Gluon Polarization From Spin Asymmetry Measurements At PHENIX

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(on behalf of PHENIX Collaboration)

Outline

- Probing ΔG through polarized p+p collisions
- PHENIX detectors
- Asymmetry measurements at PHENIX
- Constraints on ΔG and global fit
- Outlook

ΔG Through Polarized p+p

- ΔG is a quantity of interest after 'spin crisis' (EMC results at 1988)
- Accessible from polarized DIS via scaling violations
  - 2^{nd} order interactions
  - Not enough polarized data
- Polarized hadron collisions : an ideal laboratory to study polarized gluon distributions
  - Pertubative QCD with collinear factorization are the tools to describe the data
- RHIC is a unique facility to study polarized p+p collisions at various energies (62.4, 200, 500 GeV)

PHENIX Detectors

π^0, η, γ detection

- Electromagnetic Calorimeter (PbSc/PbGl):
  - High pT photon trigger
  - Acceptance: $|\eta|<0.35$, $\varphi = 2 \times \pi/2$
  - High granularity (~10*10 mrad^2)

π^+/π^-, $e^\pm$, $h^\pm$

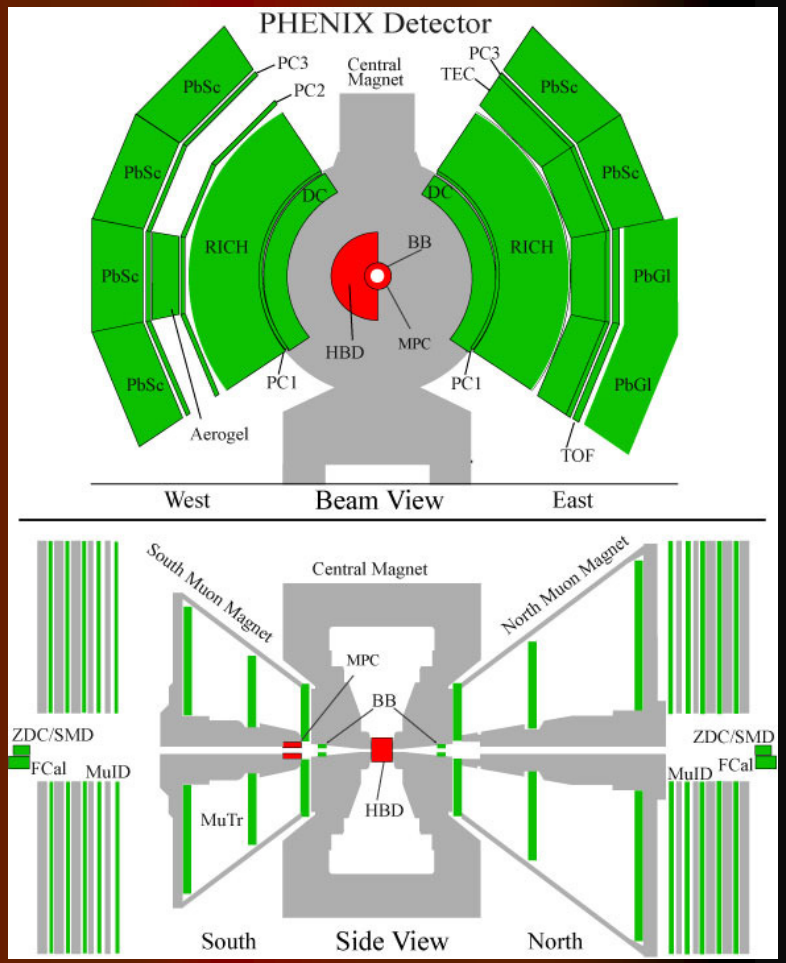
- Drift Chamber (DC)
- Ring Imaging Cherenkov Detector (RICH)

Relative Luminosity

- Beam Beam Counter (BBC)
  - Acceptance: $3.0< \eta <3.9$
- Zero Degree Calorimeter (ZDC)
  - Acceptance: ±2 mrad about beam axis

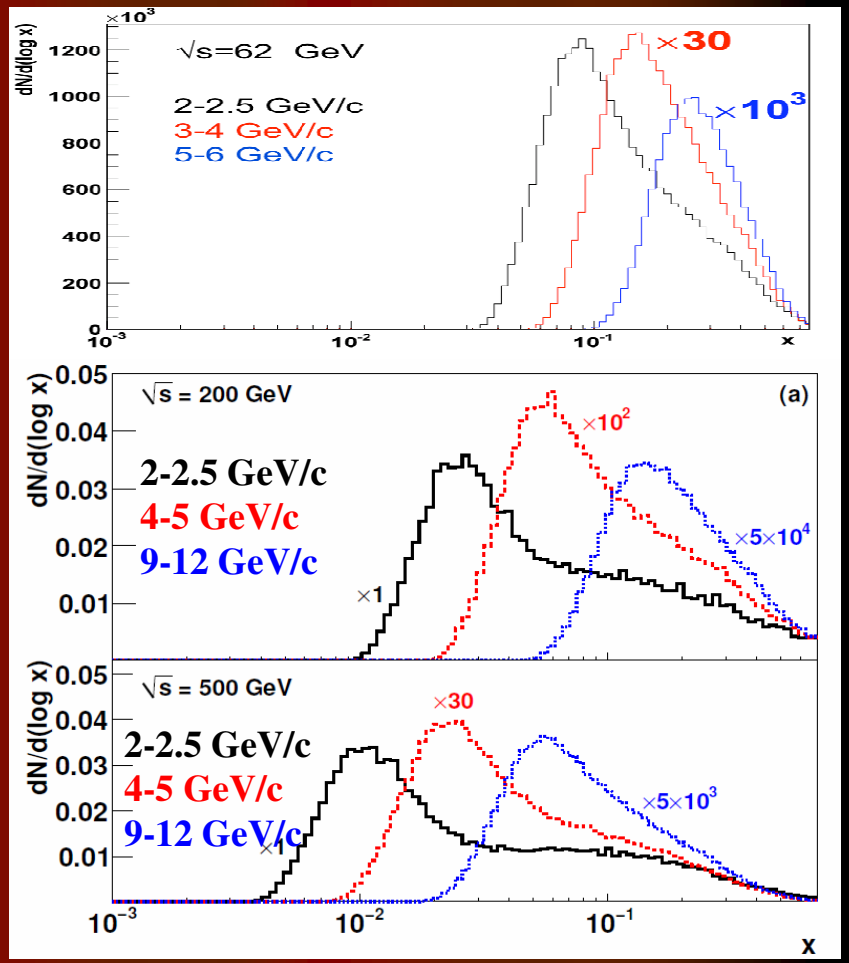
Focus : High granularity and high bandwidth

Compromise : Acceptance

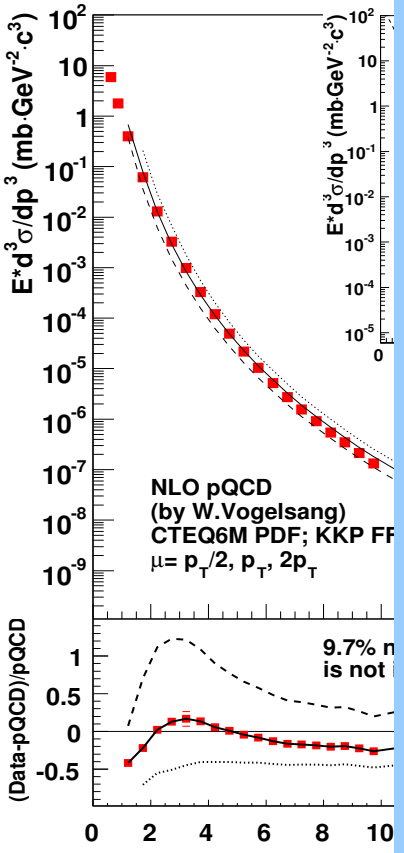


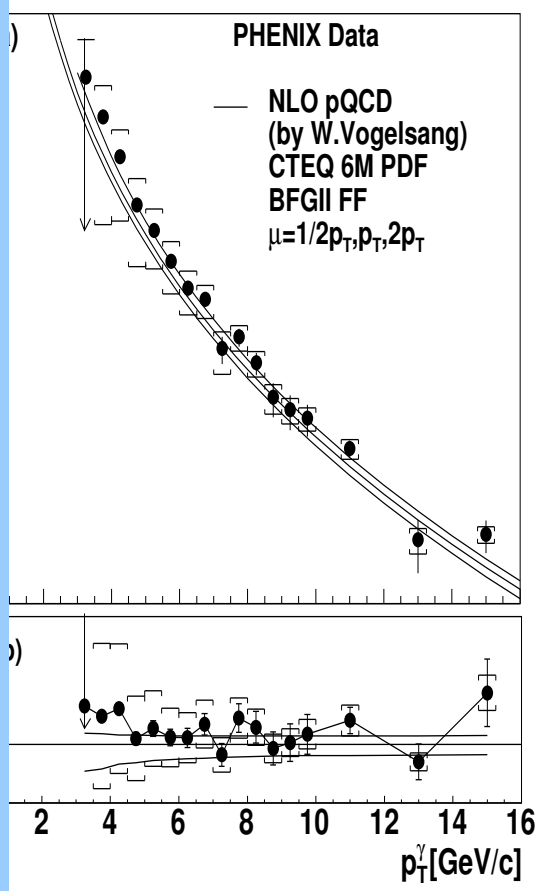
Probing Bjorken-x Ranges

- Parton momentum fraction correlated with produced hadron p_T shown
- For similar p_T of produced hadrons, higher energy probes a lower x range
  ($x_T = 2p_T/\sqrt{s}$)
- Asymmetries at various center of mass energies will constrain polarized gluon distribution $\Delta g(x)$ over wide range of x



Unpolarized Cross-Section and pQCD





- Framework of pQCD and collinear factorization are tested with cross-section measurements
- NLO pQCD calculations and data are in good agreement
- pQCD can be used to extract gluon polarization information from asymmetries

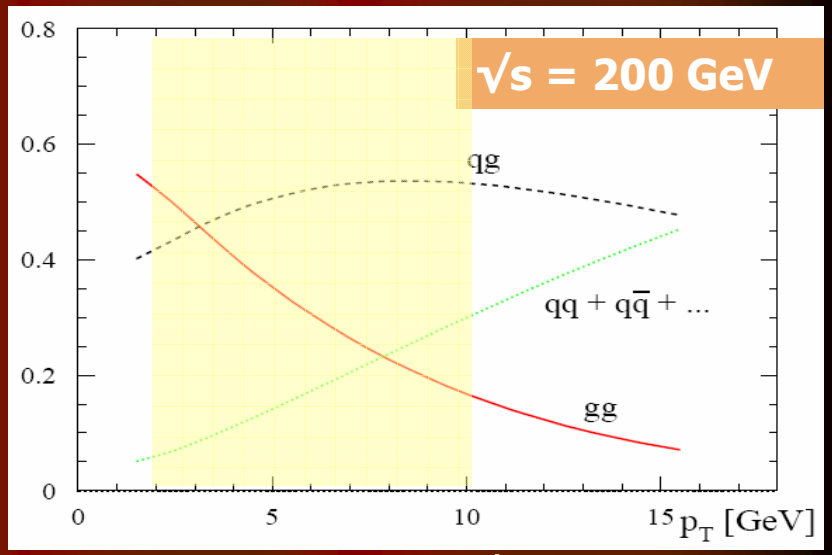
π^0: PRD76 (051106), … $\sqrt{s}$=62.4 GeV (012002), $\sqrt{s}$=200 GeV

Neutral Pion A_{LL}

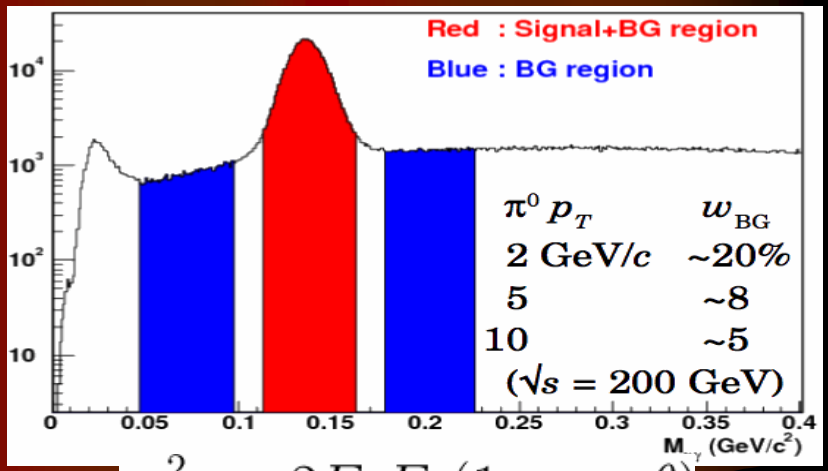
- The most abundant probe at PHENIX, triggered using electromagnetic calorimeter
- $\pi^0 \rightarrow \gamma\gamma$ BR ~ 98.8 %
- Well developed method over the years
- Sensitive to gluon polarization in leading order

- Reconstruct invariant mass from photons in calorimeter and identify pion counts
- Combinatorial background determined from sidebands
- Asymmetry is corrected for background

$$A_{LL}^{\pi^0} = \frac{A_{LL}^{\pi^0+BG} - w_{BG} A_{LL}^{BG}}{1 - w_{BG}}$$

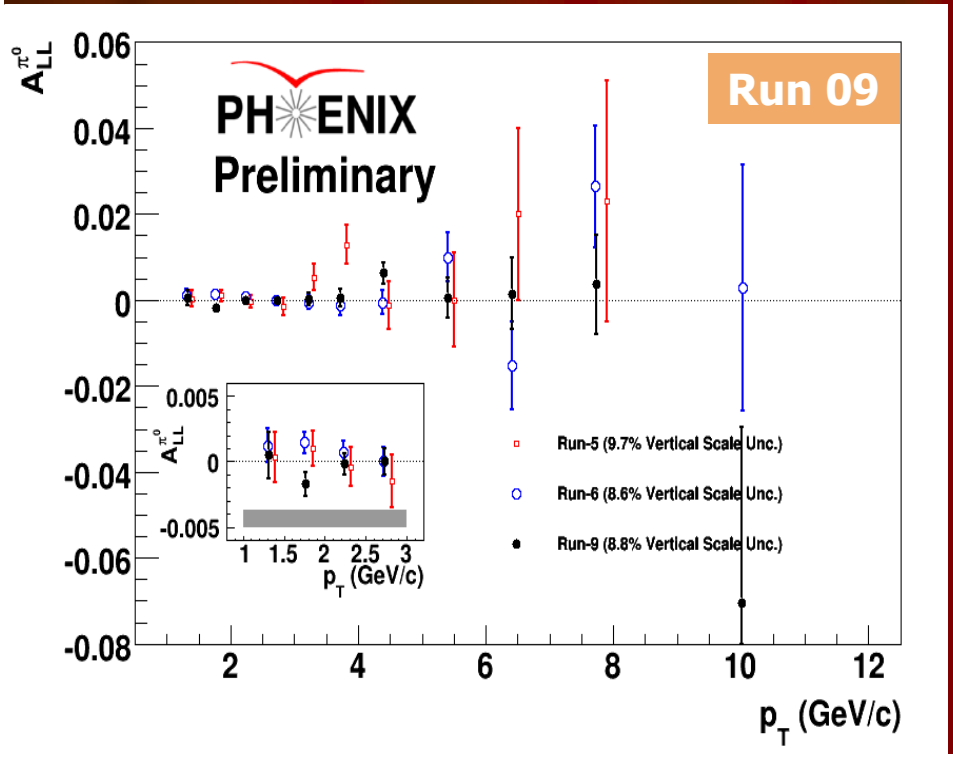


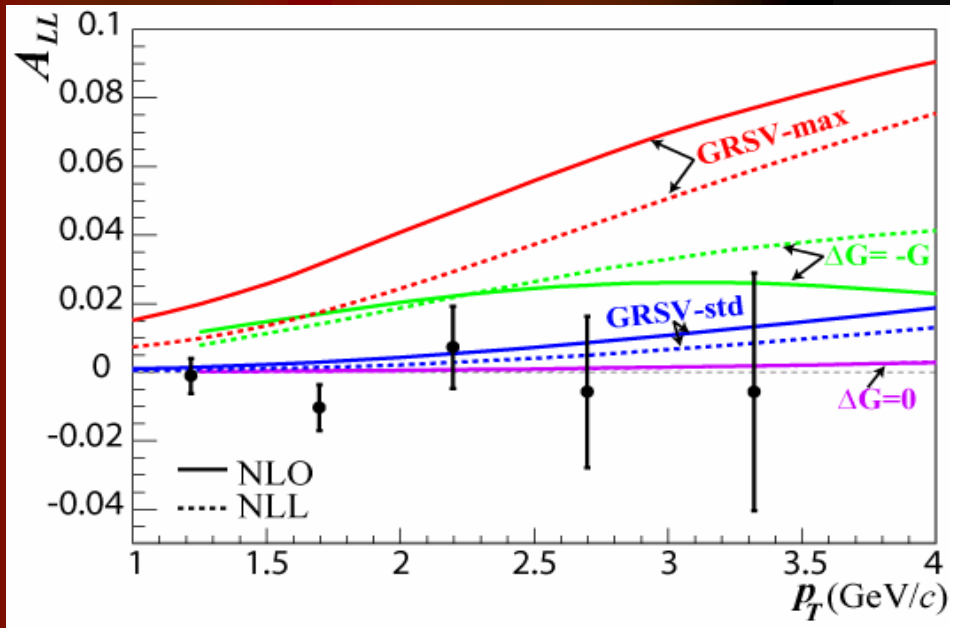
Partonic contributions



$$m_{\pi^0}^2 = 2E_1E_2(1 - cos\theta)$$

Neutral Pion A_{LL}



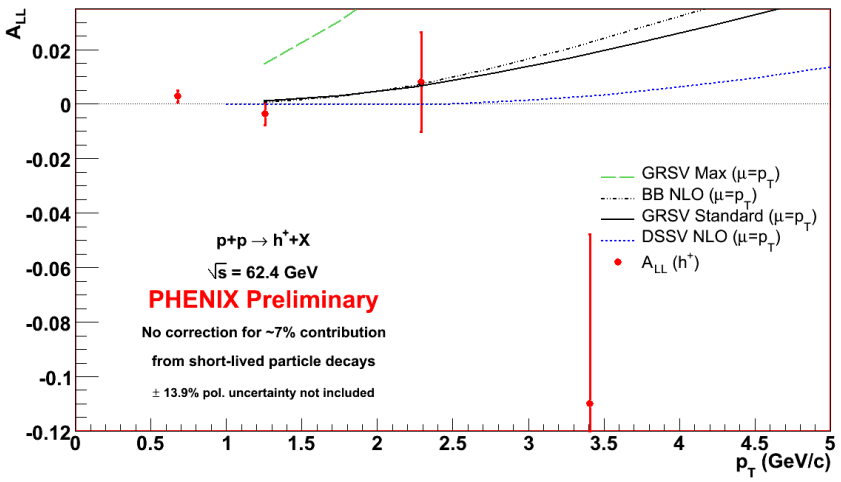


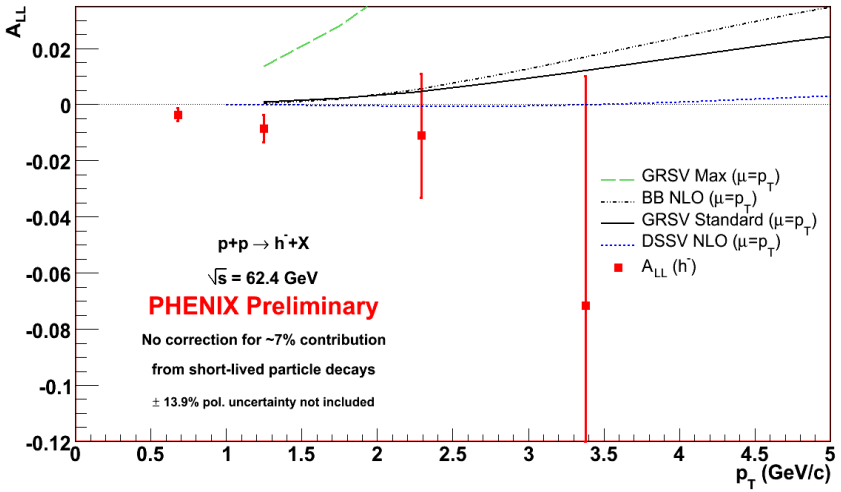
Phys. Rev. D 79, 012003 : √s = 62.4 GeV

Year	<P_B> (%)	<P_Y> (%)	$L_{analyzed}$ (pb^{-1})	FOM (P^4L)
2005	50	49	2.5	0.15
2006	56	57	6.5	0.66
2009	57	57	14	1.5

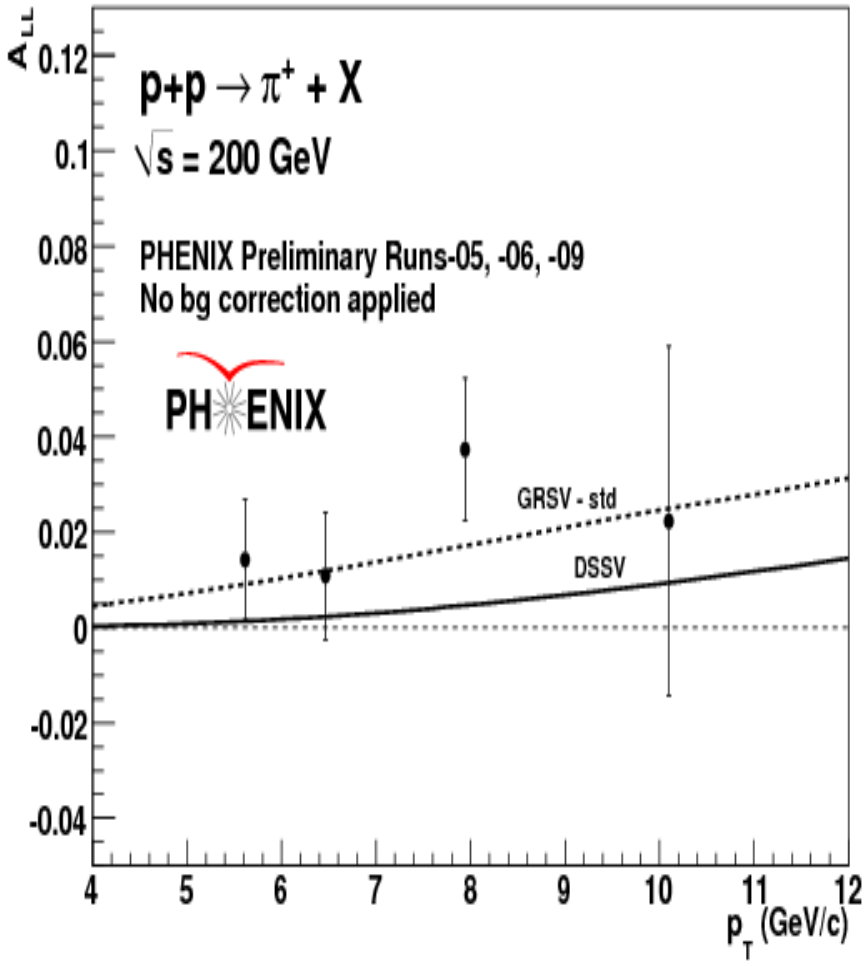
Charged Hadron A_{LL} : $\sqrt{s}$ = 62.4 GeV

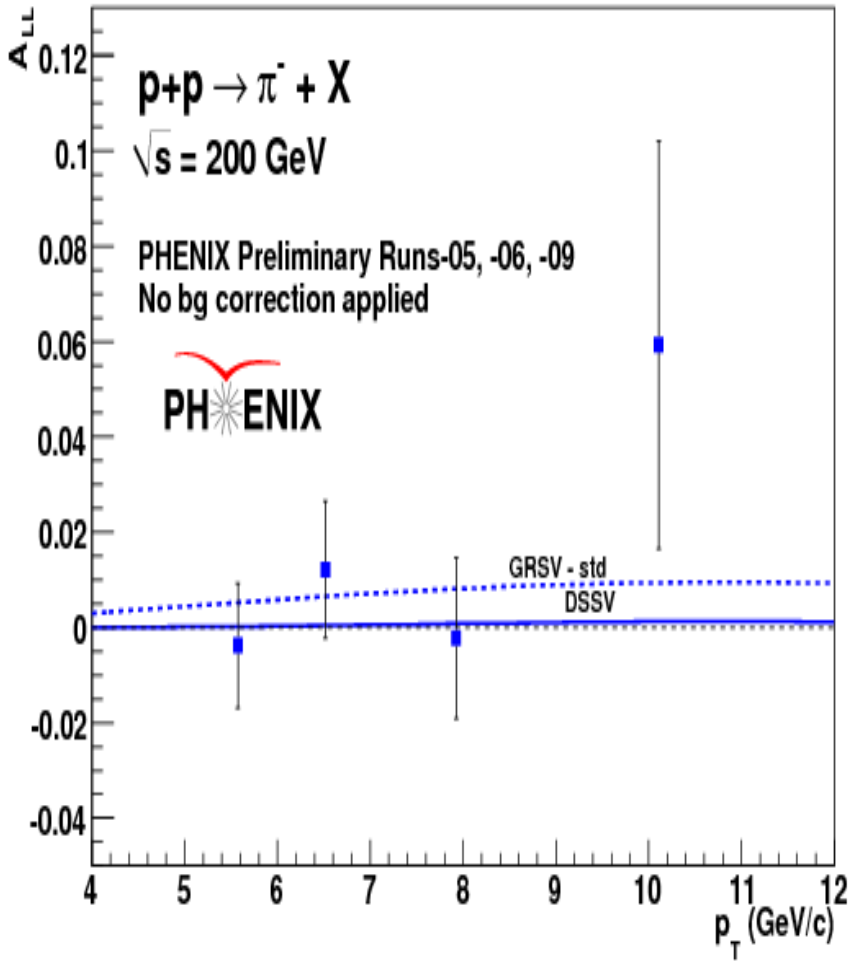
- Hadron counts (N^{++}, N^{+-}) from PHENIX tracking detectors (DC, PC)
- Electron/positron background eliminated by RICH veto
- Asymmetry corrected for background from decays
- Polarization of both beams ~ 48%
- Polarization uncertainty ($\delta\langle P_B.P_Y\rangle/\langle P_B.P_Y\rangle$ = 13.9 %) is an overall scale uncertainty
- Uncertainty of relative luminosity $\delta R \sim 1.4\times10^{-3}$ is neglected in comparison





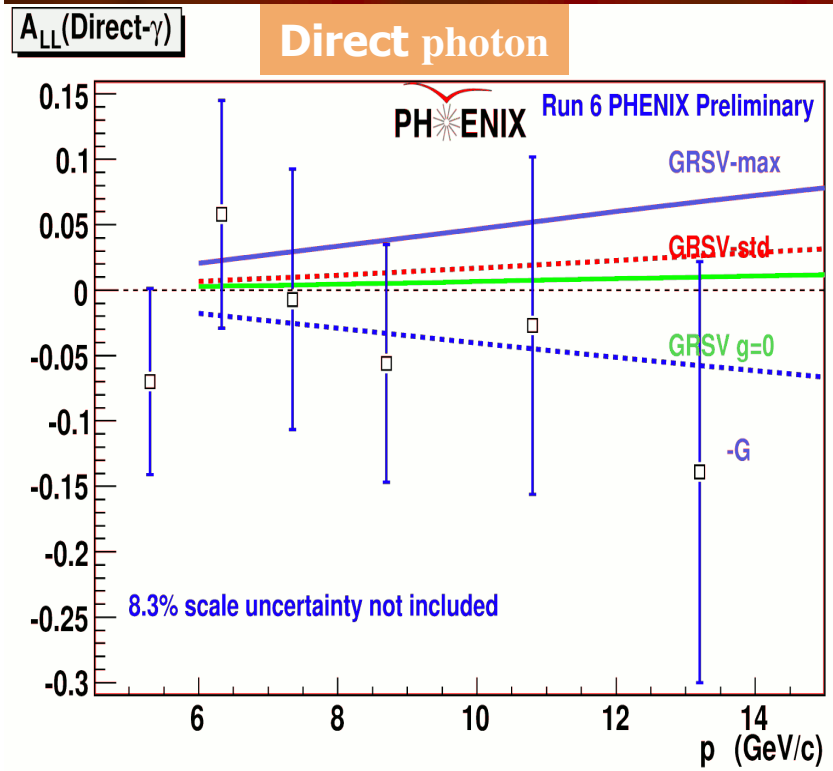
Charged Pions





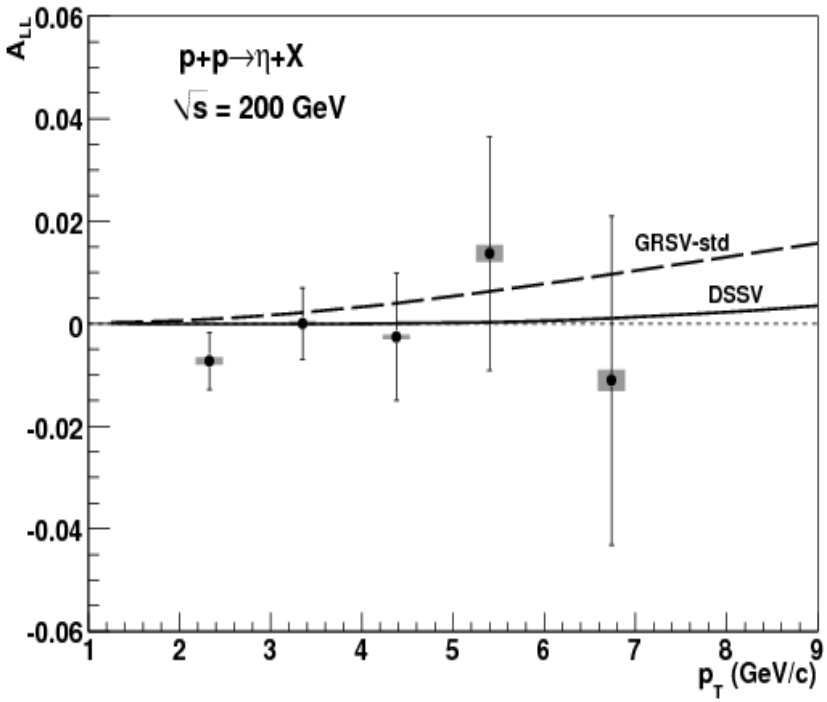
Other Probes

Direct photon



- Linear in ΔG
- No fragmentation, clean channel
- Isolation cut for photon candidates
- Large decay background, pion decay candidates excluded

η A_{LL} : Phys. Rev. D 83, 032001

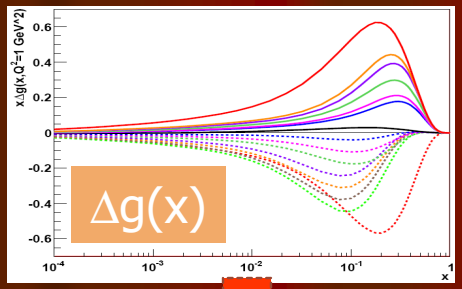


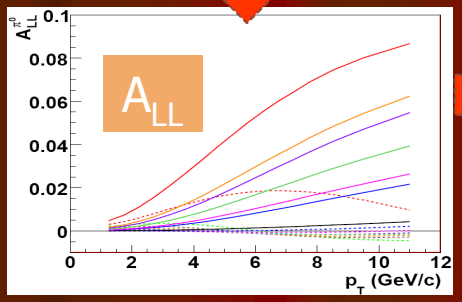
- Photons from electromagnetic calorimeter
- Invariant mass reconstructed (similar to neutral pion analysis)

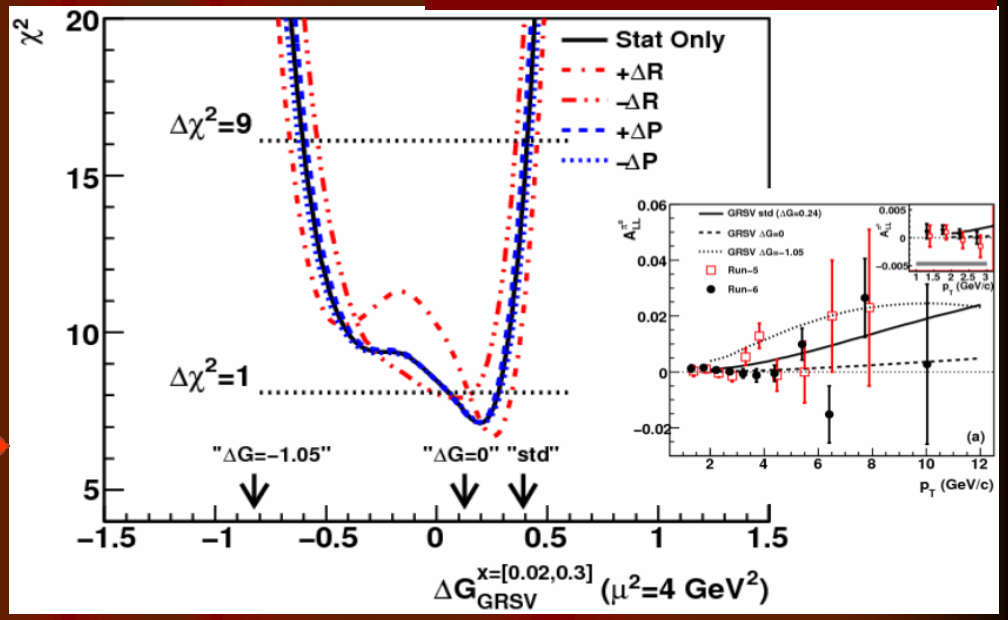
Constraining ΔG Using A_{LL}

- Generate Δg(x) for varying ΔG in GRSV fit, generate A_{LL} for each Δg(x) , calculate χ^2 for each expectation curve

PRL 103, 012003 (2009)







Considering only the statistical uncertainty :

$$\Delta G^{[0.02,0.3]}_{\mathrm{GRSV}} = 0.2 \pm 0.1\ (1\sigma)\ \text{and}\ 0.2^{+0.2}_{-0.8}\ (3\sigma)$$

Global Analysis : ΔG

- PRL**101**, 072001(2008) by de Florian, Sassot, Stratmann, and Vogelsang
- NLO global analysis using polarized DIS, SIDIS and pp results
- PHENIX $\sqrt{s}$ = 200 and 62 GeV π^0 data used
- RHIC data significantly constrain ΔG in range $0.05<x<0.2$
- Parameterize PDF's, calculate A_{LL} with best fit PDF's and calculate $\chi 2$ with world experimental data, calculate best fit of ΔG

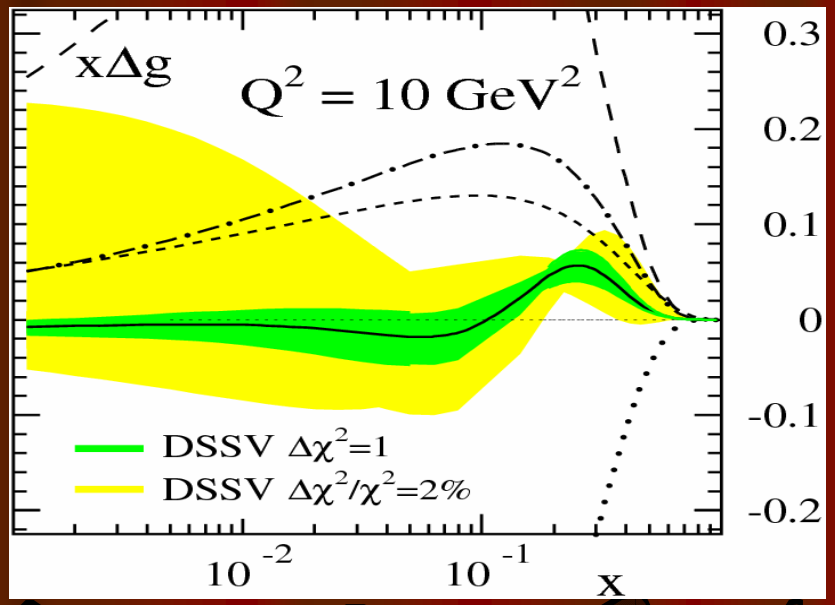


TABLE II. First moments $\Delta f_j^{1,[x_{\min}\to 1]}$ at $Q^2 = 10\ \mathrm{GeV}^2$.

	$x_{\min} = 0$ best fit	$x_{\min} = 0.001$ $\Delta\chi^2 = 1$	$x_{\min} = 0.001$ $\Delta\chi^2/\chi^2 = 2\%$
$\Delta u + \Delta\bar{u}$	0.813	$0.793^{+0.011}_{-0.012}$	$0.793^{+0.028}_{-0.034}$
$\Delta d + \Delta\bar{d}$	−0.458	$-0.416^{+0.011}_{-0.009}$	$-0.416^{+0.035}_{-0.025}$
$\Delta\bar{u}$	0.036	$0.028^{+0.021}_{-0.020}$	$0.028^{+0.059}_{-0.059}$
$\Delta\bar{d}$	−0.115	$-0.089^{+0.029}_{-0.029}$	$-0.089^{+0.090}_{-0.080}$
$\Delta\bar{s}$	−0.057	$-0.006^{+0.010}_{-0.012}$	$-0.006^{+0.028}_{-0.031}$
Δg	−0.084	$0.013^{+0.106}_{-0.120}$	$0.013^{+0.702}_{-0.314}$
$\Delta\Sigma$	0.242	$0.366^{+0.015}_{-0.018}$	$0.366^{+0.042}_{-0.062}$

Outlook

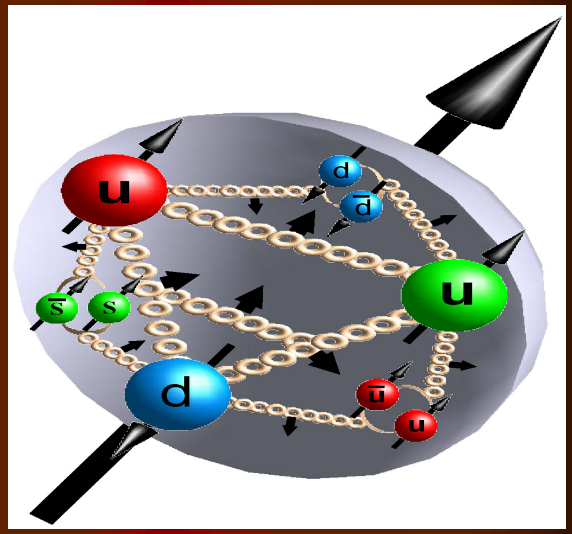
- PHENIX π^0 data puts strong constraint on ΔG
- Various channels to probe ΔG are available at PHENIX
  - A variety of probing channels puts better systematic constraint on ΔG
  - Charged hadron and charged pion A_{LL}'s could be useful in determining sign of ΔG
  - Several recent results could be used in future global analysis
- Looking at uncertainty at low-x region from DSSV plots, it's essential to extend the x-range probed experimentally
- A_{LL} results at $\sqrt{s}$ = 62.4 GeV and 500 GeV from PHENIX will extend the horizon of probed x-range
- Higher luminosity, higher polarization and possible trigger for charged pions/hadron will improve data significantly

Thank You

Backup

What is ΔG

- Proton is a complex and composite structure of quarks and gluons with total spin of ½ ħ
- Total spin of a composite structure is sum of individual components (spin and orbital angular momenta of quarks and gluons)
- Contribution of spin of all gluons in proton to the total spin of proton is ΔG (difference between same and opposite helicity gluons in polarized proton)

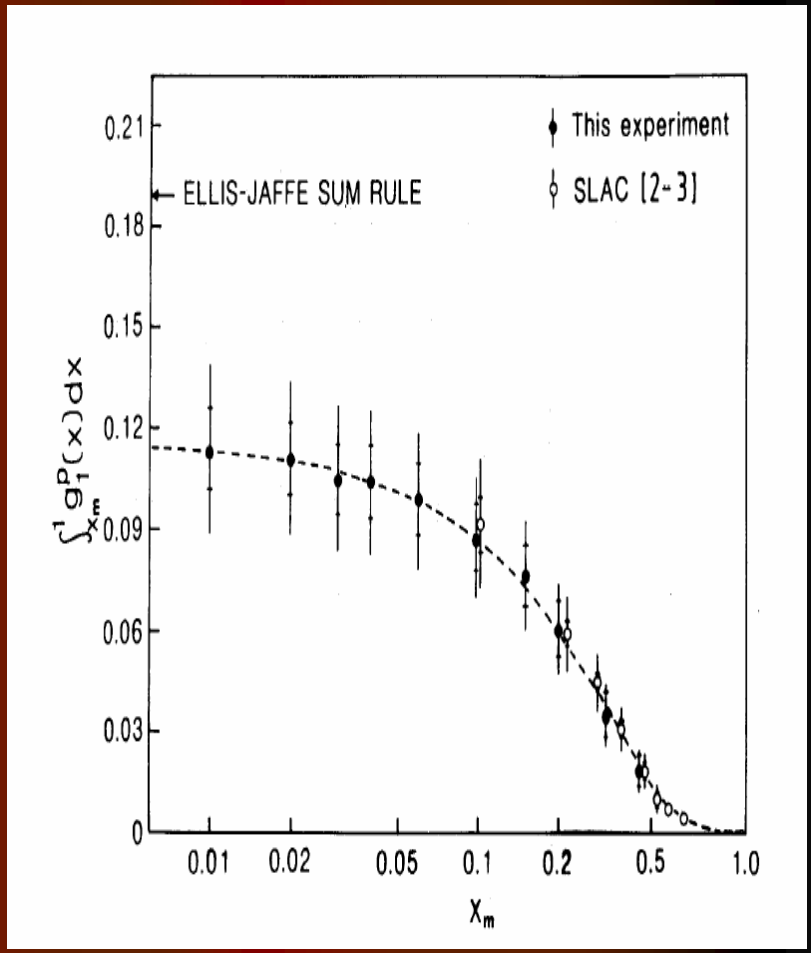


$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma(Q^2) + \Delta G(Q^2) + L_q(Q^2) + L_g(Q^2)$$

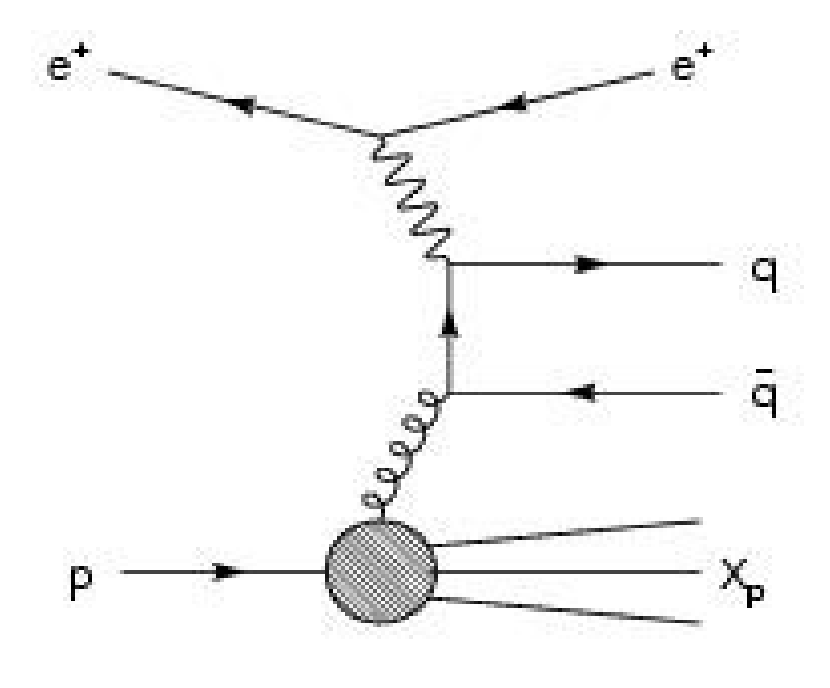
$$\Delta G = \int_0^1 dx \Delta g = \int_0^1 dx [g_+(x,\mu^2) - g_-(x,\mu^2)]$$

Why is it interesting

- Quark spin was expected to carry bulk of the proton spin (~ 60%)
- EMC at CERN conclusively measured quantities (spin-dependent structure function) that contradicted the scenario of quark spin being the major contributor to the proton spin
- EMC and SLAC results indicated quark spin $\Delta\Sigma$ contribute a fairly small fraction (~25%) to the proton spin
- Is ΔG a major contributor?



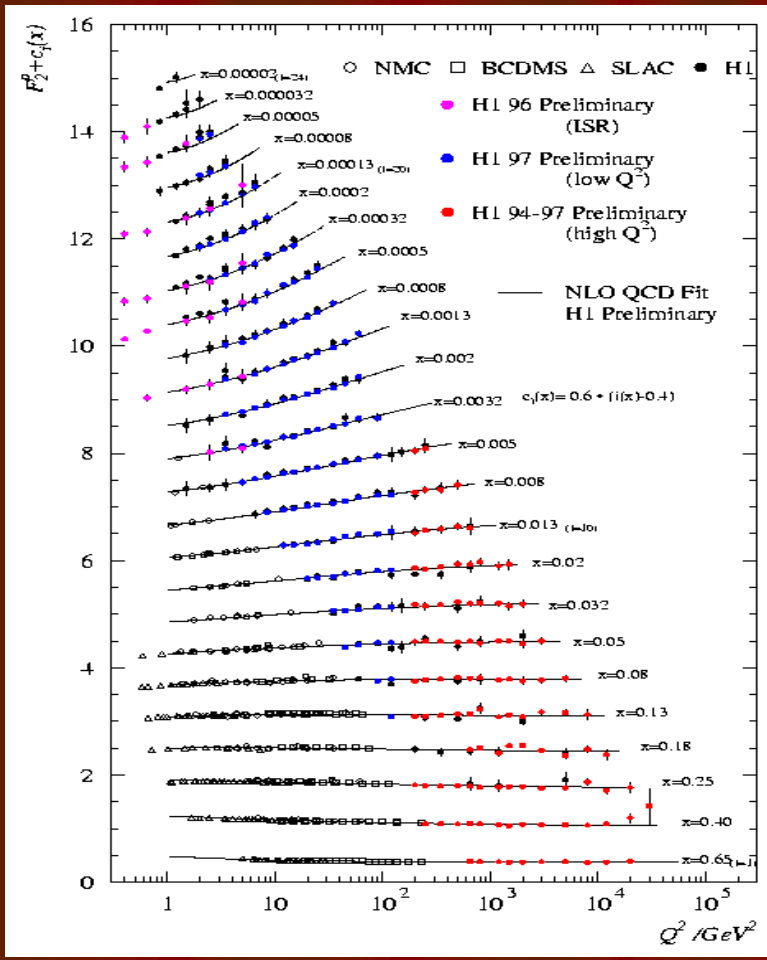
Polarized DIS and Gluon PDF



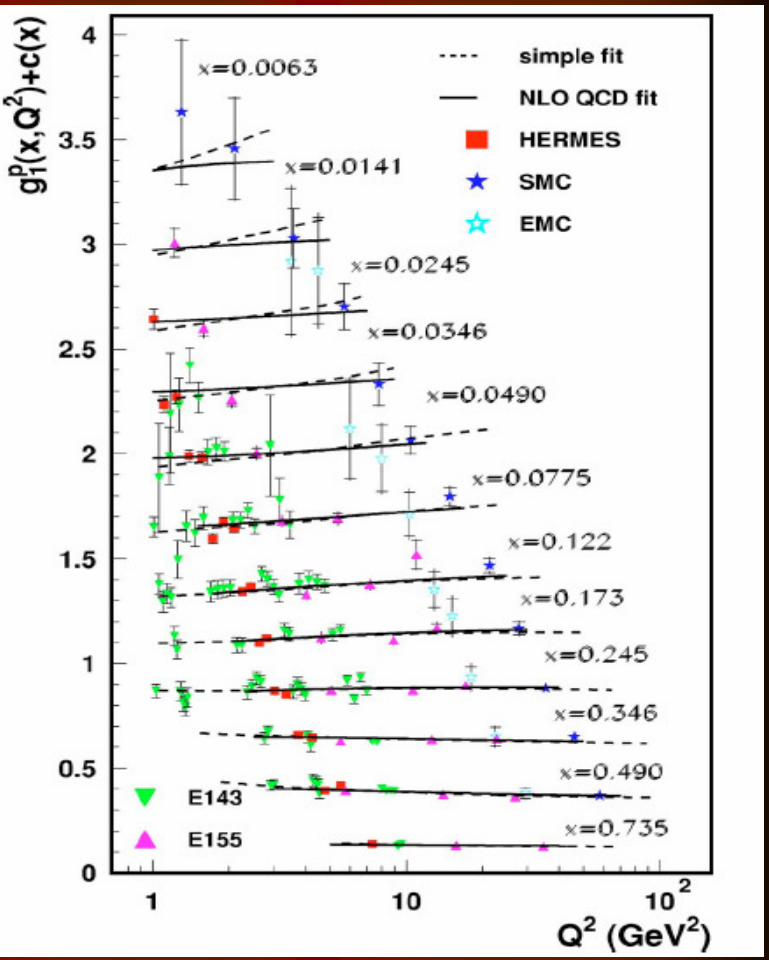
- Polarized DIS were not ideal for accessing gluon spin
- Gluons interact only via strong force and leptons do not interact via strong force
- DIS probe gluon distributions only at higher order interactions

Unpolarized and Polarized Structure Functions

Unpolarized



Polarized



- **Not enough data in different x,Q^2 range from pDIS exp to extract information with satisfactory accuracy**

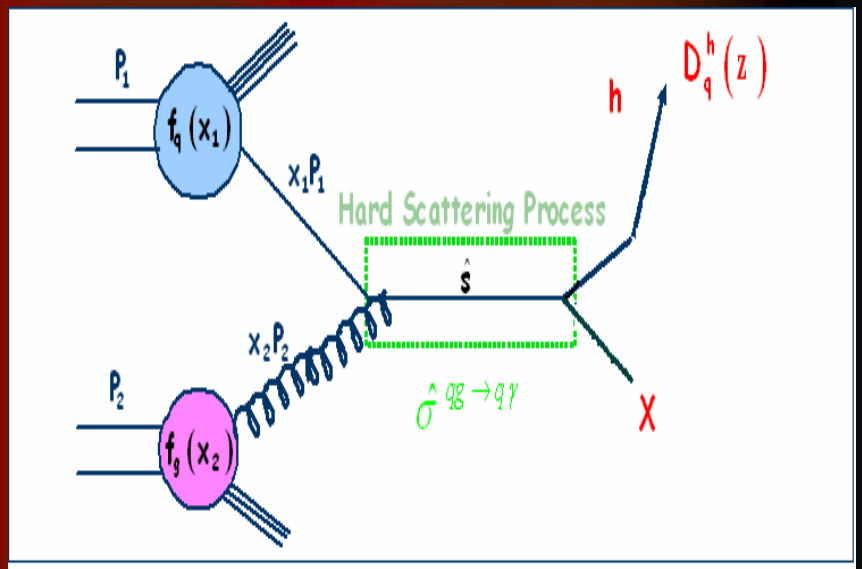
Polarized DIS and Gluon PDF

- Bjorken Scaling : At intermediate x and high Q^2, g_1^p independent of Q^2 and scales with x
- Scaling violation is observed as positive slope at low x and negative slope at high x
- Q^2 evolution using DGLAP (Dokshitzer-Gribov-Lipatov-Altarelli-Parisi) equation were used to extract $\Delta g(x)$ (*an indirect way)

$$\frac{d}{dt}\begin{pmatrix}\Delta\Sigma\\ \Delta g\end{pmatrix} = \frac{\alpha_s(t)}{2\pi}\begin{pmatrix}A_{qq} & 2fA_{qg}\\ A_{gq} & A_{gg}\end{pmatrix}\begin{pmatrix}\Delta\Sigma\\ \Delta g\end{pmatrix}$$

Collinear Factorization

- A pp scattering process can be factorized into long-term and short-term components as shown.
  - **PDF's of partons (long)**
  - **pQCD hard scattering cross-section (short)**
  - **Fragmentation function of hadronization (long)**
- Verify framework by comparing un-polarized cross-section with calculations



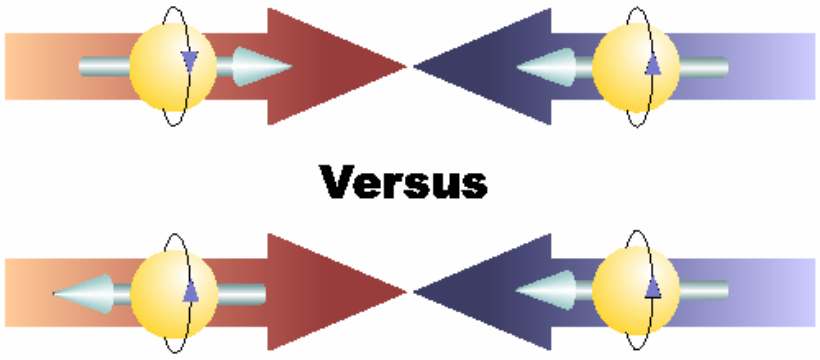
$$\sigma(pp \to hx) \propto f_q(x1) \otimes f_g(x2) \otimes \hat{\sigma}^{qg \to hX} \otimes D_q^h(z)$$

PDF PDF pQCD FF

Double-Spin Asymmetry (A_{LL})

- Difference between two helicity dependent cross-sections of particle production as a fraction of the un-polarized cross section

- ++ same helicity
- +- opposite helicity
- N^{++} (N^{+-}) are counts of a produced species of particle with same (opposite) helicity configuration of the colliding particles
- R = Relative Luminosity
  = L^{++}/L^{+-}



$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

$$A_{LL} = \frac{1}{P_1 P_2} \frac{N^{++} - RN^{+-}}{N^{++} + RN^{+-}}$$

Accessing ΔG from A_{LL}

- Using collinear factorization, one can express the pp cross section as :

$$\sigma(pp \longrightarrow hX) = \Sigma_{a,b,c} \int dx_a\, dx_b\, dz_c\, q_a(x_a) \otimes q_b(x_b) \otimes \hat{\sigma}^{ab \longrightarrow cX} \otimes D_c^h(z_c)$$

- The asymmetry is defined as :

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

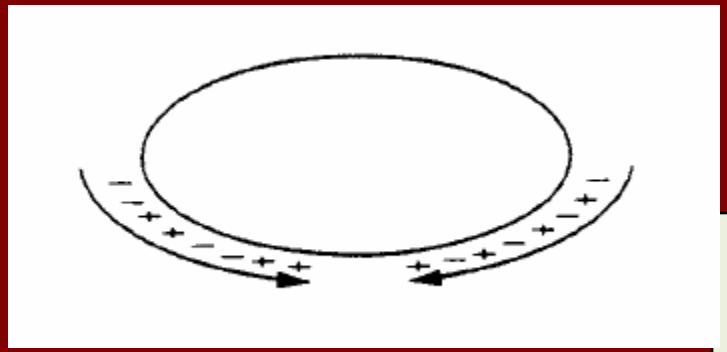
- Assuming a partonic process of *qg* scattering A_{LL} can be related to the PDF's as :

$$A_{LL} \propto \frac{\Sigma_q \Delta q(x1) \otimes \Delta g(x2) \otimes \Delta\hat{\sigma}^{qg \to hX} \otimes D_q^h(z)}{\Sigma_q q(x1) \otimes g(x2) \otimes \hat{\sigma}^{qg \to hX} \otimes D_q^h(z)}$$

- With information of quark PDF's from DIS, of fragmentation functions from SIDIS and e^+e^- experiments and calculating partonic cross-section using perturbative QCD, gluon polarization information Δg is extracted

RHIC as a Polarized p-p Collider

- Proton bunches filled with alternating spin combinations



- Four different spin patterns are u
- Siberian snakes rotate spin vecto perturbations cancel on subseque stable)
- Spin Rotators allow polarization t longitudinal or horizontal as requ
- Absolute (H-jet) and relative (pC p measurements

Longitudinal Spin Running in PHENIX

Year	√s [GeV]	L [pb^{-1}] (recorded)	Pol. [%]	FOM (P^4L)
2003	200	0.35	27	0.0019
2004	200	0.12	40	0.0031
2005	200	3.4	49	0.20
2006	200	7.5	57	0.79
2006	62.4	0.08	48	0.0042
2009	200	14	57	1.5
2009	500	14	39	0.21

DSSV : Input world data

- Data selection:

"classic" inclusive DIS data

routinely used in PDF fits

! $\Delta q + \Delta \bar{q}$

semi-inclusive DIS data

so far only used in DNS fit

! flavor separation

first RHIC pp data (never used before)

! Δg

experiment	data type	data point fitted
EMC, SMC	DIS	34
COMPASS	DIS	15
E142, E143, E154, E155	DIS	123
HERMES	DIS	39
HALL-A	DIS	3
CLAS	DIS	20
SMC	SIDIS, $h^{\pm}$	48
HERMES	SIDIS, $h^{\pm}$	54
	SIDIS, $\pi^{\pm}$	36
	SIDIS, $K^{\pm}$	27
COMPASS	SIDIS, $h^{\pm}$	24
PHENIX (in part prel.)	200 GeV pp, π^0	20
PHENIX (prel.)	62 GeV pp, π^0	5
STAR (in part prel.)	200 GeV pp, jet	19
TOTAL:		467

467 data pts in total (10% from RHIC)